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19th century curved board roofs in Bavaria

XIX-wieczne dachy krążynowe w Bawarii

Keywords: Timber structures, Curved board roof, Construction process

Słowa kluczowe: konstrukcje drewniane, dachy krążynowe, proces konstrukcyjny

1. INTRODUCTION

Roofs relying on laminated arched trusses are one of the most idiosyncraic construction types of 19th century timber building. This kind of structure never got widespread, but nevertheless, it received a lot of attention and discussion in the contemporary literature and re-appeared every now and then in the built reality.

New building types such as railway stations, riding halls, or theatres frequently required wide-span roofs; together with the dwindling supply of timber and the influence of neo-classical architecture (calling for low-pitched roofs), this forced German architects and carpenters to move away from the classical „liegender Stuhl" constructions (having a reputation of being extremely timber-consuming) and to try purlin roofs. It was hoped that new construction types would require less timber and would therefore save money and reduce the risk of conflagration.The experiments in structure are particularly well reflected by the development of the curved board roof.

2. 19th CENTURY DEVELOPMENT OF THE CURVED BOARD ROOF TRUSS

The early history of the curved board roof around 1800 has been traced very well in [1]. Our present study tries a tentative extension of this work until the late 19th century. It is based on the extensive contemporary printed sources on the subject, as well as a survey of several existing buildings employing this roof type.

The 19th century technical literature proves that curved board roof trusses are a recurring subject until the end of the century. Typically, Philibert de l'Orme is cited with his book "Nouvelles inventions pour bien bastir et á petis fraiz" of 1561as the inventor of the laminated arched roof truss [2]. In Germany, and particularly in Prussia, this standard historical genealogy is primarily due to David Gilly, who launchend a big propaganda in favour of arched roof trusses around 1800 [3]. It is not the topic of the present study to find out whether Gilly's etymology was correct or not. Anyhow, it should be noted that arches made up of several layers of curved boards – set on edge and nailed together – are the principal construction of 16th-19th century wooden vaults, so that not "re-invention" was really necessary to bring the idea back to the constructional practice of Gilly's time.

In the early 19th century, we find a diversity of different constructions in the general category of curved board arched trusses. David Gilly himself has left a record of constant experimentation and improvements in his various treatises. His first curved board roofs employed pairs of arched rafters which were notched into a board on edge forming a kind of „ridge purlin" (Fig. 1, no. 93 A). However, observed damages in this kind of structure led him to an improved version: Now, he preferred rafters halved across each other at the apex and resting on top of the purlin (Fig. 1, no. 93 B and C). This was also presumed to improve the longitudinal stiffness of the roof ([1], p. 53).

In 1801, the Saxonian master carpenter Leopold Leideritz dealt at length with Gilly's roofs and published his thoughts in his textbook on carpentry. His main objection against Gilly's constructions was the use of short boards. Leideritz recognised correctly that rafters made up of short pieces joined together were considerably less stiff than rafters consisting of as few pieces as possible ([5], p. 173). This was an essential argument against both Gilly and his purported "ancestor" de l'Orme because both of them had praised the cheapness of the curved board arches which could be made up of short, otherwise "useless" pieces and would not require large scantlings. Furthermore, Leideritz criticized Gilly's ridge "purlin". He considered it as insufficient for the required longitudinal

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stiffening of the roof. Leideritz recommended, to join the individual arched trusses in ridge direction by horizontal braces at half-elevation (mortise-and-tenon connection). In the last volume of his textbook, which appeared only in 1818, Leideritz added further criticizm. This time, his argument was based on his own experience with an arched roof erected on a barn ([6], p. 214). The experience confirmed him in his opinion that Gilly's original designs were defective.

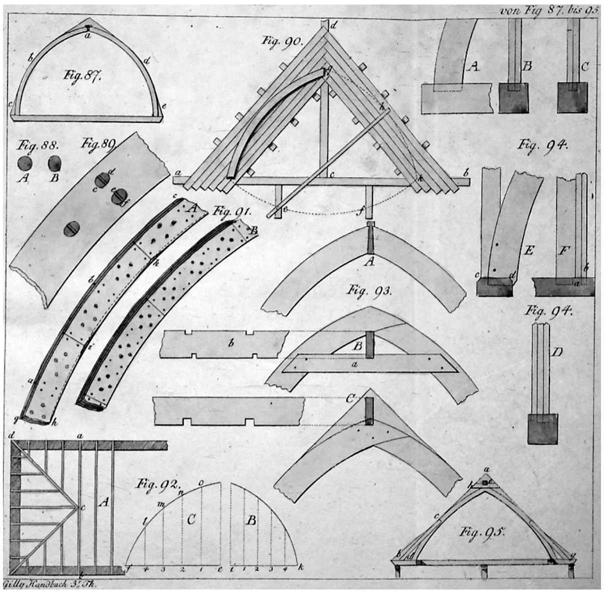

Fig. 1. David Gilly's arched roof truss designs [4]

Gilly himself could not entirely repel these arguments. He himself added more longitudinal members to his roof designs in his publications after 1800. In his riding hall erected at Berlin-Kreuzberg (erected in 1799/1800, see [1], p.217; cf. Fig. 2), Gilly used the laminated arches as the load-carrying truss for an ordinary roof with straight rafters. While this roof did not differentiate between "principal" and "ordinary" rafters, but consisted of a sequence of identical rafter pairs, longitudinal connection was provided by a pair of purlin-like beams resting on the collar beam. At the rafter feet, additional inclined struts were added; these also clasped a purlin-like longitudinal member. In addition to this, Gilly added more wind bracing in the plane of the rafters. Note, however, that this roof did not contain a ridge purlin. Friderici – the editor of Gilly's posthumously published third volume of the "Landbaukunst" from which our illustration is taken – emphasized that collar beams, braces and rafters were "intimately joined" in this roof ([4], p.175, §91).

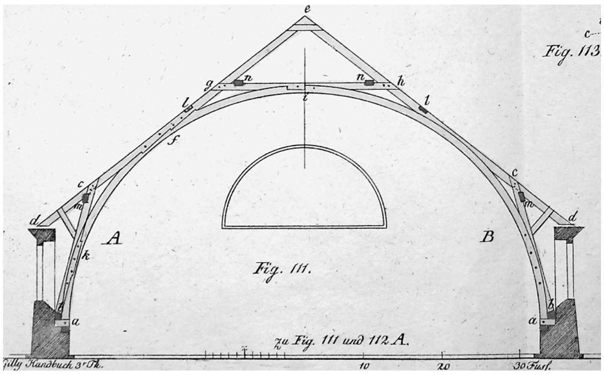

Fig. 2. Berlin-Kreuzberg, riding hall of the „Leibhusaren-Regiments" [4]

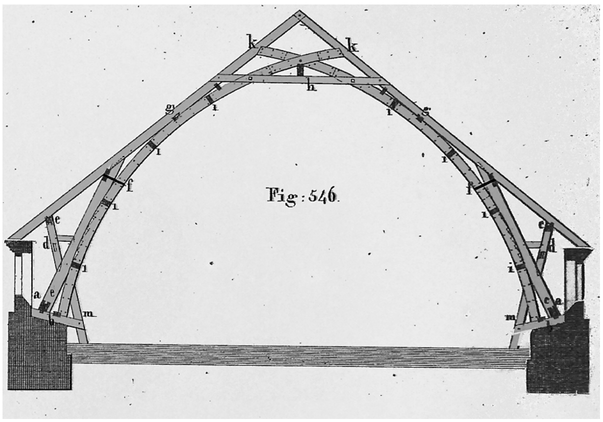

Fig. 3. Riding hall at Berlin, Husarenstraße. [7] pl. LXXIII, Fig. 546

A later example, the riding hall at Husarenstraße in Berlin (according to [1], p.64, this was probably erected in 1818, cf. Fig. 3), shows a similar development of Gilly's original scheme. In this roof, the arches of two neighbouring trusses are connected to each other by a whole set of horizontal braces at regular intervals. The inclined struts are bolted down to the arches ([7], p. 61). At the apex, the pair of arched rafters cross each other and abut against the straight rafters forming the outer shape of the roof. The straight rafters – originally only introduced in order to eliminate the difficulty of getting a tight cover on a curved roof surface – are thus increasingly integrated into the load-bearing structure of the roof truss. Originally, Gilly had added short straight extensions on top of the principal curved rafters for the purpose of flat roof surfaces; now, the rafter is an integral part of the scheme.

The time's tendency towards low roof pitches inspired another innovation: Since the arch requires considerable height in order to work properly, the outer shape of the building can only be adjusted to the neo-classical idea of a low roof pitch if the eaves are raised above the rafter feet (cf. [1], p. 59). Another important roof with arched trusses built at roughly the same time is the roof over the central pavilion of the Polytechnic of Vienna (Fig. 4, erected 1816-18).

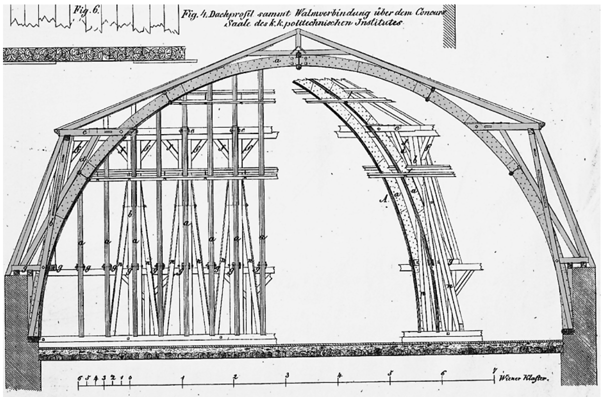

Fig.4. Vienna, Polytechnical School, roof over the main pavilion ("Concours-Saal"). [8] Fig. 4, pl. XXII

This roof, construction details of which were published by Johann Gierth in his 1840 textbook ([8], p. 306), has been preserved and recently restored. In this roof, the individual arches are joined by pairs of strong boards which clasp the arches from above and below. Furthermore, inclined wind-bracing was added to each arched truss. The roof, a mansard-shaped pavilion roof, also has a crippled collar beam which joins the arched rafter in its middle to the outer rafters. The collar beams are supported by a purlin resting on an inclined strut, a construction which is highly reminiscent of the traditional „liegender Stuhl" . The inclined strut is present only in every second rafter pair, so that this roof is one of the earliest arched roofs which differentiates between „principal" and „ordinary" rafters.

Further development was brought about for the arched board roofs by Karl Friedrich Schinkel, who had studied at Gilly's „Bauakademie". The roof over Schinkel's Berlin „Schauspielhaus am Gendarmenmarkt" (erected 1818-22) combined all the improvements and innovations of the preceding two decades (Fig. 5). It is evident that the curved board roof now tends towards the structure of a fully developed purlin roof.

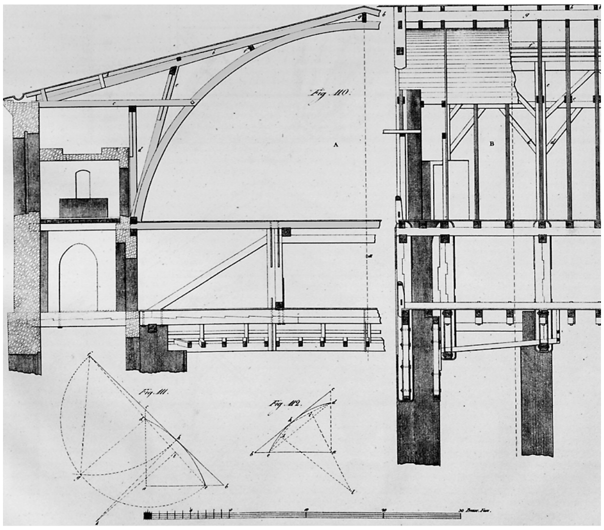

Fig. 5. Berlin, Schauspielhaus, roof over the painters' hall. [12] pl. XII, Fig. 110

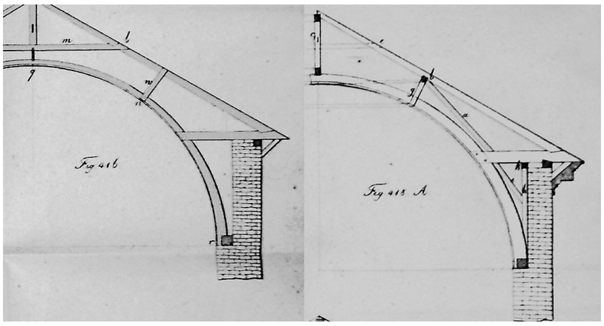

Fig. 6. and Fig. 7. [9] pl. XXIII

France did not take part in Gilly's "curved plank roof" frenzy; France had its own version of that, namely the "laminated arched roof" developed by the colonel Amand-Rose Émy. Émy's arches consisted of layers of flat boards placed on top of each other and bent into arched shape. His scheme was employed in the construction of several military halls in France, staring in the 1820ies. Émy's arched trusses are beyond the scope of the present contribution. However, it is important to note that the scheme was also well-known to German engineers, albeit from publications rather than from built examples (publications included a German translation of Émy's 1837-41 textbook on carpentry). Some influence may have been exerted by this French counterpart. We are particularly inclined to believe that the increasing use of radial braces clasping the arch were inspired by the French construction. Examples of Gilly-type roof trusses with radial braces include two roof designs as published by Ludwig Friedrich Wolfram in 1824, cf. [9] (Fig. 6 and Fig. 7).

Perhaps even closer in structure to Émy's arched trusses is a later roof designed by Schinkel, his riding hall erected for Prince Albrecht (1831, Fig. 8). This Gothic Revival structure is covered by means of pointed plank arches, joined to the outer straight rafters by Émy's radial struts.

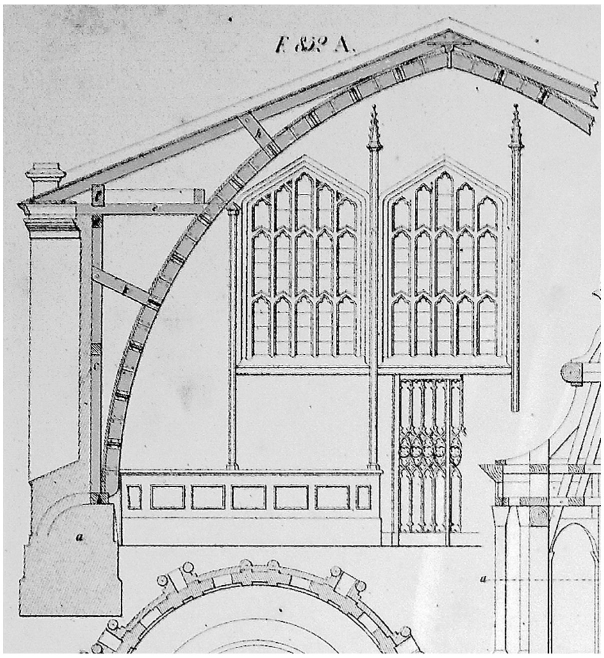

Fig. 8. Berlin, Prince Albrecht's riding hall. [10] Fig. 852, pl. 126

It took a while before the curved plank roof, originating at Berlin, finally arrived in Bavaria as well. Publications such as Johann Michael Voit's treatise of 1825 may have contributed [11]. Voit had been Gilly's student and was infected by Gilly's ideas. When he became a civil servant at Augsburg, he spread the innovative ideas there and believed in the general superiority of arched girders. In contrast to his contemporaries who tended to make the arches semi-circular rather than pointed except in „Gothic" style buildings, Voit remained faithful to the pointed shape as favoured by Gilly himself (Fig. 9).

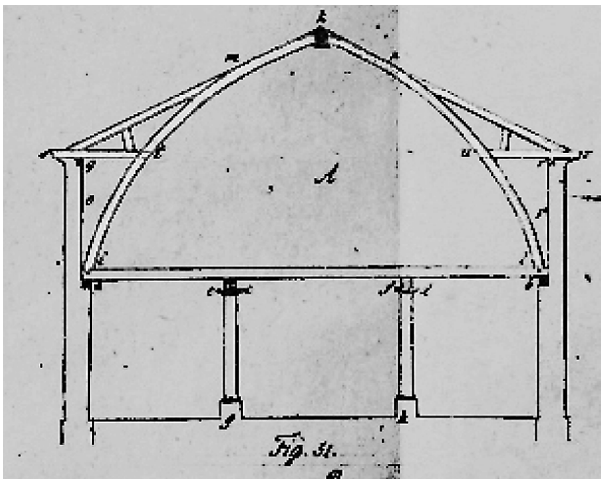

Fig. 9. recommended arched roof for storage buildings and packhouses. [11] Fig. 51

Curved board roof structures were also contained in the most influential German textbook on carpentry, namely, Johann Andreas Romberg's book of 1833 [7] (an extended second edition appeared in 1847). Romberg published, in addition to Gilly's original designs, the roof construction of Schinkel's „Schauspielhaus". The fact that the second edition of Romberg's work was dedicated to Leo von Klenze testifies Romberg's close ties to engineering circles at Munich. We may therefore safely assume that the details of the curved board roofs were familiar to the Munich architectural protagonists. Unfortunately, the 1833 edition of Romberg's book contained only minimal text, so that we do not know whether Romberg considered the curved plank roof as advantageous then or not.

Apart from Romberg's book, the single most influential publication on wood construction of that time was probably the series of „Vorlegeblätte für Zimmerleute", published under Beuth's direction at Berlin. While the first few editions (starting in 1827) were only intended for the use of the civil servants of the Prussian "Technische Deputation für Gewerbe" (the ministry of economic affairs), later editions were available to the general public after 1835 [12]. The "Vorlegeblätter" ("pattern designs") recommended curved plank roofs for all types of buildings requiring an unobstructed space. Detailed data on required scantlings were provided, as a function of span ([12] p. 9, pl. XII).

Critical attitudes towards the curved plank roof clearly emerge in the 1840ies. Carl August Menzel (1842) explicitly advised against any use of them. He also claimed that they were in fact only rarely executed in practice. However, for anybody who would insist on the application of the scheme, Menzel has special advice. Arched trusses are recommended only as subsidiary support for ordinary roof structures ([13] p. 136-137).

We do not know whether this change of opinion was brought about by a knowledge of Paul Joseph Ardant's careful scientific analysis of curved roof trusses of 1840 [14]. However, it is clear that Ardant's book found a quick reception not only in France, where it brought about the rapid end of the Émy arch, but also in Germany (a German translation appeared in 1847). Ardant had proven scientifically – both by an examination of experimental results obtained by Reibell in the late 1830ies and by careful application of Navier's theory of bending – that all the arched girders were much more flexible than trusses consisting of straight members. Even though Ardant did not explicitly speak against the arched trusses ([14], p. 9-13), it was now evident that they were both economically and structurally inferior to ordinary roof trusses such as Italian purlin roofs which had been used for centuries.

In the following decades, curved plank roofs continued to be carried out occasionally. The technical literature generally reflected Ardant's analysis; the older types of curved plank roofs were still reprinted again and again, but now this was generally accompanied by a note that these structures were mainly of historic interest. The widely read textbook of Breymann and Lang of 1870 [15] recommended arched girders only in the context of an overall purlin roof. As an example, Lang presented a roof over a gymnasium at Karlsruhe which he had executed himself (Fig. 10). Lang's roof has principal rafters and a horizontal iron tie to carry the thrust. The arch appears as a subsidiary reinforcement of the roof truss; it helps to support the purlins by means of radial struts. Longitudinal stiffening of the structure is achieved by wind braces at the principal rafters.

In his comprehensive textbook on construction, Rudolf Gottgetreu wrote in 1890 in retrospect about the development

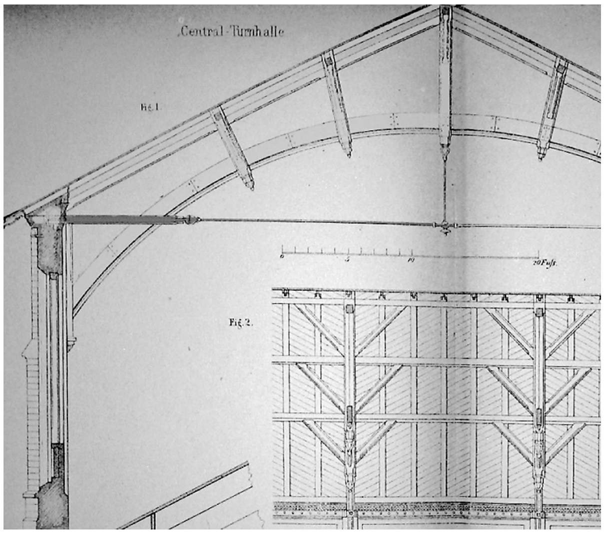

Fig. 10. Turnhalle Karlsruhe (1869). [15] Anhang Fig. 1

of the curved board roof: „Probably no other roof structure has been the object of more experimentation than the curved plank roof" ([16], p. 217).

3. SURVIVING EXAMPLES

3.1 Neuburg/Danube, Castle

The western aisle of the castle at Neuburg/Danube (Bavaria) is covered by a low-pitch roof that rests on curved plank trusses. The roof which spans 18,5 m has not received much attention until now, even though it is well preserved and one of the biggest surviving German curved board roof trusses (Fig. 11). The roof was erected in 1824 under the direction of Bernhard v. Morell, a former student of Weinbrenner at Karlsruhe, and built by the Neuburg court carpenter Wildenauer [17].

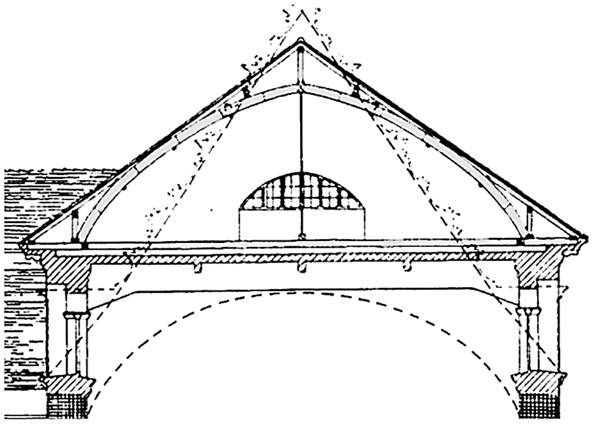

Fig. 11. Schloss Neuburg, Westflügel [17] S. 240

The roof has slightly pointed arches and a continuous ridge purlin. They consist of three layers of boards, connected by iron nails. No distinction between principal rafters and ordinary rafters has been made, all rafter pairs are identical. At the apex of the arch, the arched rafters are tenoned into a purlin, and the rafter feet are notched into a sill. The straight rafters which carry the roof cover are also continuous; they show a sawtooth-shaped step joint where they touch the arches, as in Fig. 2. The ridge of the roof is supported by a ridge purlin, which in turn rests – by means of intermediate struts – on the "ridge purlin" of the arches. The pair of ridge purlins – at the apex of the arch and straight rafters – constitute a kind of stiff “truss” parallel to the axis of the roof and provide longitudinal stiffening. Further longitudinal purlins support the straight rafters at their lower end; these purlins are carried by vertical struts. In the upper region, another intermediate purlin is provided, which is supported from the haunches of the arch. Further longitudinal stiffening is provided by pairs of strong boards clasping the arches, as shown in Fig. 4. These pairs are held together by bolts at irregular spacing. On second sight, it turns out that in fact the roof has continuous tiebeams only in every forth axis. A singular device are the iron ties by which the continuous tiebeams are suspended from the ridge truss.

The overall design clearly reflects the contemporary state of development: Traditional elements of Gilly’s curved plank roof are present, but more recent improvements have also been adopted. The joint between the straight rafter and the curved rafter is reminiscent of Gilly’s designs (Fig. 2). The pointed arch follows Gilly faithfully. On the other hand, more recent developments such as the paired boards clasping the arches are not only found in the Vienna roof (cf. Fig. 4), but also in the roughly contemporary wooden dome which Georg Moller erected above the catholic church at Darmstadt (1822-27, [18]). Morell and Moller may have met during their studies at Karlsruhe; maybe Morell got the inspiration for the curved plank roof at Neuburg there. Their common teacher Weinbrenner was explicitly against curved plank roofs, as early as 1809 ([1], p.110).

3.2 The harbour master’s house and bard at Beilngries

In 1836, the Bavarian king Ludwig I. orderd to commence the construction of the canal betweeen the rivers Danube and Main. The canal was opened in 1843. The responsible engineer for the entire project was Heinrich Friedrich von Pechmann [19]. Interestingly, several curved board roofs were executed in the context of the canal. Here, we discuss the so-called harbour master’s house and the adjacent barn at the former canal port (now dry) at Beilngries, Bavaria. Today, only the iron crane and the revetment of the former harbour basin testify of the former purpose of the buildings.

All the buildings in the architectural context of the canal were designed by Pechmann, but examined and revised architecturally by a commission at Munich headed by Leo von Klenze. Design drawings dated 1837 show the general plan of the harbour, as well as sections and elevations of the individual buildings (cf. Fig. 12 for a sample). The design drawings present conventional “stehender Stuhl” trusses and curved board roofs as alternatives. Fig. 12 shows a comparative example of an original drawing of a curved board roof in the harbour master’s house in Bamberg.

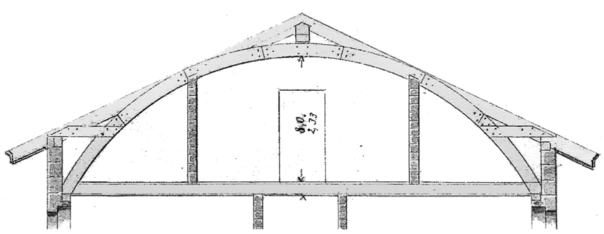

Fig. 12. Canal lock attendant’s house at lock no. 100, Bamberg (Planarchiv Eisenbahnmuseum Nürnberg)

Both builings in Beilngries were also actually carried out with arched roof trusses, which have been preserved (Fig. 13 and 14).

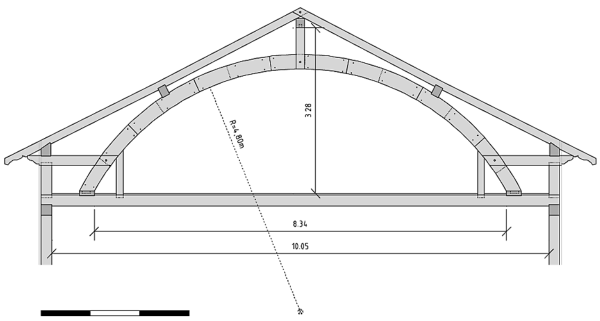

Fig. 13. Beilngries, barn

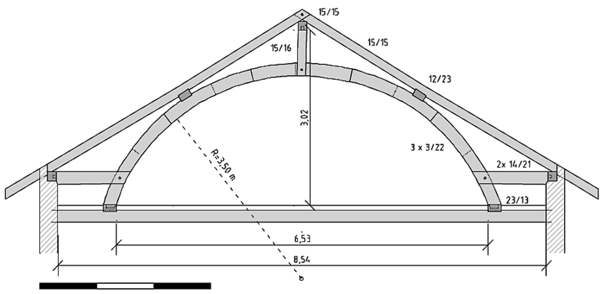

Fig. 14. Beilngries, harbour master’s house

The ground floor of the harbour master’s house (1837-43) contained the harbour master’s living quarters. The attic is empty today, however, the design drawings show that a small chamber was planned here as well. Probably, this was a heatable chamber which contained a “economic stove” as invented by Pechmann. No traces of the attic chamber or of the stove are recognizable today.

The barn was erected in 1850 (archival note, Verkehrsmuseum Nürnberg). Both houses have a rectangular ground-plan and a ridge roof. The outer straght rafters are notched into a sill, supported by intermediate and ridge purlins, and halved across each other at the apex. The purlins are carried by curved plank arches, which rest on sills which are notched onto the tiebeams. The attic has raised eaves. The feet of the straight rafters are anchored at the arches by twin ties which clasp the arches and are attached by means of bolts. A pair of boards also clasps the apex of the arch and attaches it to the ridge purlin.

Both roofs thus have continuous tiebeams. The longitudinal stiffening of the roofs is achieved by the purlins; only in the barn, we find additional wind braces. The arches are part of principal trusses; every third pair of rafters is a principal truss. The board arches are assembled by means of iron nails. At the barn, the nails are clearly visible. At each side of joint, there are two nails. An additional pair of nails is in the middle of each board.

The barn has a span of 8,54 m and is therefore somewhat larger than the harbour master’s house (span 6,53 m). This difference in span is probably the reason why the arches of the barn consist of three layers of boards, whereas those of the harbour master’s house have only two layers. The arches are semi-circular. The length of the boards is 1,50 m, their height 28 cm at the barn. At the harbour master’s house, the boards are 1,60-1,70 m long and 22 cm high.

The curved board roof system was quite probably selected because an unobstructed roof space was desired. Both buildings require economic storage space. In constructive detail, the roofs at Beilngries are clearly different from Gilly's original layouts, and they reflect the state of the development around 1840 well. Johann Andreas Romberg published similar roofs in the 1833 edition of his textbook ([7] pl. LXXII).

3.3 Brine reservoir at Klaushäusl (Grassau)

The brine reservoir at Grassau-Klaushäusl is part of the brine pipeline from Reichenhall to Rosenheim (constructed in the second decade of the 19th century). It is part of one of the seven pumping stations of that pipeline. The brine arrived at a lower container and was pumped up to a tank high on the hill. This tank was covered by the building which we discuss here (for a historyof the pipeline and its technical equipment, see [20-22]).

The present building (Fig. 15) dates back to a reconstruction of 1875 [23], and its roof is therefore an interesting late example of a board arch roof. Already Gilly himself had suggested the use of his timber arch roofs for building like brine reservoirs, pumping stations or steam engine shelters (cf. [1], p. 34).

The one-storey building has a rectangular plan, ashlar masonry walls, and is covered by a ridge roof. The width of the single room in the interior is 6,20 m. The continuous rafters are notched into sills at their base, supported by two intermediate purlins, and halved across each other at the top. The purlins rest on semicircular board arches. The arches are tenoned into a sill. The eaves are again raised, resulting in a low-pitch aspect from the outside. Between the sill and the wall-plate, a crippled tie-beam is clamped, which joins the arch to the rafter feet. The arch is attached to this brace by a bolt.

The lack of a tiebeam is balanced by the thickness of the walls. They are 72 cm thick. Longitudinal stiffening of the construction is provided exclusively by the purlins. There are 7 arches, and there are 2 rafter pairs in each bay between the arches, so that the arches can be called principal trusses. The purlins rest on massive gable triangles.

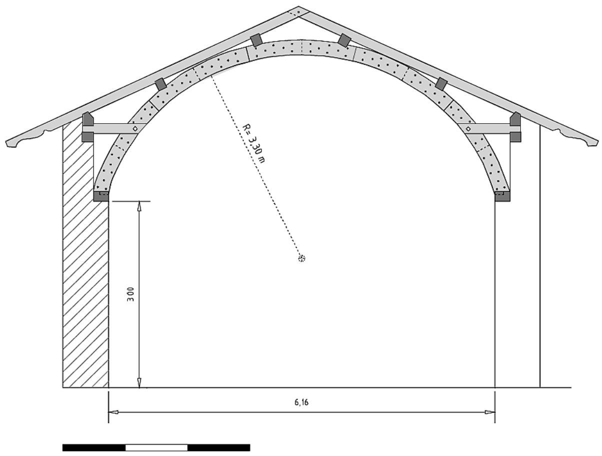

Fig. 15. Grassau (Bavaria), Klaushäusl, brine reservoir

The construction of the arches follows Gilly's suggestions precisely: At the joints, we find iron nails, whereas each board is fixed to the layer beneath it by a treenail in its center as well. The arches consist of three layers of boards. Each layer is 4 cm thick. The boards are approximately 1,20 m long and 25 cm high. Compared to the scantlings suggested by Friderici in 1811 in a detailed list ([4], p. 129), we find the dimensions as built are considerably stronger.

The roof contains all the „modern" elements which we have encountered in the review of the 19th century literature on arched timber frames. Arches and rafters are separated, the overall roof layout is a purlin roof. The construction is not dramatically different from the harbour master's house built 40 years earlier. This testifies to the decreasing attention which the scheme received during the second half of the 19th century. Compared to Lang's gymnasium roof of 1869 ([15], cf. Fig. 10), the almost contemporary roof at Klaushäusl looks a bit old-fashioned.

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Abstract

Curved roof trusses made up by boards were first introduced by Philibert de l'Orme in 1561. However, de l'Orme's invention did not succeed much until it became popular in the late 18th century. David Gilly, a civil servant in the Prussian administration of buildings, promoted the idea by a series of propagandistic publications. In the years around 1800, a considerable number of curved plank roofs were actually built, ranging up to spans of around 20 m. While the history of these roofs is fairly well known, the later development of the curved plank roof is less known. The system was severely criticized by early engineer such as Paul Joseph Ardant in the 1840ies, and scientific arguments were put forward against it. Nevertheless, curved plank roofs continued to be used until the late 19th century. There was even some Renaissance of the scheme in the last third of the century, probably mainly due to curved plank roofs published in well-known construction manuals such as Gustav Adolf Breymann's.

We present different curved plank roofs which are still preserved in Bavaria. They cover the time range between 1824 (Neuburg / Danube, castle) and the 1870ies (brine reservoir building on the Reichenhall-Rosenheim saltworks pipeline). A considerable number of curved plank roofs has also been preserved along the canal between the Danube and the Main (1840ies), in the context of lock attendants' homes. The structures will be presented, compared to earlier curved plank roofs, and put into the context of contemporary technical literature.

Streszczenie

Krążynowe kratownice zbudowane z drewnianych elementów po raz pierwszy wprowadził Philibert de l'Orme w 1561 roku. Jednakże wynalazek de l'Orme'a został spopularyzowany dopiero pod koniec XVIII wieku. David Gilly, urzędnik państwowy w pruskiej administracji budowlanej, wypromował ten typ konstrukcji w serii publikacji. Około roku 1800 istniała już znaczna ilość dachów krążynowych, a rozpiętość niektórych z nich wynosiła nawet około 20 m. Podczas gdy historia tych konstrukcji jest dość dobrze znana, to ich dalszy rozwój już znacznie mniej. System ten był krytykowany przez ówczesnych inżynierów, takich jak Paul Joseph Ardant, w latach 40-tych XIX wieku i wysuwano przeciwko niemu argumenty naukowe. Jednakże dach krążynowy był nadal stosowany, aż do końca XIX wieku. Nastąpił nawet pewien renesans tego modelu konstrukcji w ostatnim trzydziestoleciu XIX wieku, spowodowany zapewne publikacjami na temat dachów krążynowych pojawiającymi się w dobrze znanych podręcznikach konstrukcyjnych, takich jak dzieło Gustava Adolfa Breymann'a.

My przedstawiamy inne dachy krążynowe, jakie są nadal zachowane w Bawarii. Pochodzą one z okresu pomiędzy rokiem 1824 (zamek Neuburg nad Dunajem) i latami 70-tymi XIX wieku (budowa zbiornika solanki przy rurociągu warzelni soli w Reichenhall-Rosenheim). Znacząca liczba dachów krążynowych została także zachowana wzdłuż kanału łączącego rzeki Dunaj i Men (lata 40-te XIX w.), w domach dla operatorów śluz. Konstrukcje te zostaną zaprezentowane, porównane z wcześniejszymi dachami krążynowymi i skonfrontowane z współczesną literaturą techniczną.